TECHNICAL NOTES

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No. 558

THE PERFORMANCE OF A DePALMA ROOTS-TYPE SUPERCHARGER

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SUMMARY

The results of tests made to determine the performance of a DePalma Roots-type supercharger are presented. The performance of the DePalma supercharger with atmospheric pressure at the discharge was compared with that of a hypothetical N.A.C.A. Roots-type supercharger of the same displacement. The tests were conducted at speeds from 1,000 to 6,000 r.p.m. and at pressure differences from 0 to 15 inches of mercury. The variation in clearance between the impeller tips and the impeller housing was determined for the DePalma supercharger at a speed of 2,000 r.p.m. and for the N.A.C.A. supercharger at speeds from 500 to 3,000 r.p.m. with the pressure differences for each supercharger varying from 0 to 15 inches of mercury.

The results indicate that, if warping and growing of the metals of the case and impellers are neglected, the most uniform clearances can probably be maintained for all operating conditions when the case and the impellers are constructed of metals that have the same coefficient of expansion. The results also show that the discharge and intake openings of this model of the DePalma supercharger are too small, which lowers the volumetric efficiency and impairs the performance at all speeds and pressure differences.

At high pressure difference the volumetric efficiency of the DePalma supercharger is greater when the discharge pressure surpasses atmospheric pressure than when the discharge pressure is atmospheric.

INTRODUCTION

The Committee has investigated the performance of several sizes of N.A.C.A. Roots-type superchargers by testing them in the laboratory independent of an engine and in flight in conjunction with an engine (references 1, 2, and 3).

In these tests the superchargers were operated at speeds up to 6,000 r.p.m. and at pressure ratios up to 2.25:1. The only difficulties experienced that may be attributed to this type of supercharger were caused by the change of the clearances between the impellers or between the case and the impellers when the supercharger operating conditions were changed.

Many tests of Roots superchargers with aluminum-alloy case and magnesium-alloy impellers have shown that satisfactory operation cannot be obtained over a range of pressure ratios because of clearance variation. Because magnesium-alloy impellers in an aluminum-alloy case contacted at high pressure ratios owing to high temperatures, it was believed that, if the impellers were made of a metal with a lower coefficient of thermal expansion than the metal used in the case, it would be possible to obtain good performance at the high pressure ratios when the clearances were adjusted to the minimum practicable for the low pressure ratios. A set of steel impellers was obtained for use in the N.A.C.A. Roots-type supercharger. The tests of these impellers were discontinued because they had been improperly constructed and were therefore not suitable for this work.

Later a DePalma Roots supercharger with steel impellers and an aluminum-alloy case was obtained. This supercharger was designed mainly for use on an American-Cirrus Mark III engine. Tests of this engine, with and without the superchargers, and an endurance test of the supercharger have been made by the Bureau of Aeronautics, Navy Department. The tests reported herein were made to determine the performance of the DePalma supercharger, the variation in clearance for different pressure ratios, the effect on performance of this clearance variation, and to compare these factors with those of a hypothetical N.A.C.A. Roots supercharger having the same displacement as the DePalma.

Tests of the DePalma supercharger were conducted with the intake throttled and the discharge free at speeds from 1,000 to 6,000 r.p.m., and with the intake free and the discharge throttled at speeds from 500 to 3,000 r.p.m. For both of these conditions the pressure difference was varied from 0 to 15 inches of mercury. The variation in clearance between the impeller tips and the impeller housing was determined for the DePalma supercharger at a speed of 2,000 r.p.m. and for an 8.25-inch N.A.C.A. supercharger

at speeds from 500 to 3,000 r.p.m. with pressure differences from 0 to 15 inches of mercury for both superchargers and with atmospheric pressure at the exhaust.

APPARATUS AND METHOD

Superchargers.- The DePalma supercharger is a positive displacement blower of the Roots type having a measured displacement of 0.101 cubic foot per revolution and weighing 52 pounds. Both the N.A.C.A. and the DePalma Roots-type superchargers are designed to operate at much higher speeds than the commercial Roots blower and the construction materials are lighter. The description and tests of three sizes of N.A.C.A. Roots superchargers may be obtained from references 1 and 2. The details of construction of the DePalma supercharger and the principal features in which it differs from the N.A.C.A. Roots type will be described in the present report.

The DePalma supercharger is shown disassembled in figure 1. The various parts of the supercharger case are made of an aluminum alloy. The impeller housing of the DePalma supercharger is cast in one piece and is of more rugged construction than the housing of the N.A.C.A. supercharger, which is cast in two pieces. The DePalma housing, unlike that of the N.A.C.A., is provided with a baffle plate in the inlet passage to guide the air as it enters the supercharger. The end plates are doweled and bolted to the impeller housing. In figure 1 the plate on the antigear end is shown assembled on the housing and the one on the gear end is shown assembled as a unit with the timing gears, the impellers, and the impeller shafts. Each end plate has two recesses in which are mounted the ball bearings for the impeller shafts. The plate on the gear end forms a cover for the timing gears. To each end plate is bolted a cover plate that forms a compartment through which oil can flow and in which some oil is retained for lubricating the bearings and gears.

Figure 2 shows an impeller from the N.A.C.A. supercharger described in reference 1 and one from the DePalma supercharger. The DePalma impeller is steel, forged to the desired shape and is made in two parts welded together along the tips. A steel shaft with splines on each end is welded in the center of the impeller and the finished shape is obtained by machining and grinding. The maximum wall

thickness of the impeller is three-sixteenths inch near the center and the minimum is three thirty-seconds inch at the tips. The impeller is 6.34 inches long and 5.58 inches in diameter.

The DePalma supercharger has one pair of gears that maintain the proper phase relation between the impellers and transmit the torque from one impeller shaft to the other, whereas the N.A.C.A. supercharger is provided with a pair of timing gears and a pair of speed-increasing gears. The hub of one of the gears of the DePalma supercharger has a slotted projection for direct driving from the engine. In service installations a coupling, which is made of laminated steel and held in place by a pin, fits into this slot. For the present tests this drive was replaced by a stub shaft, bearing, and bearing retainer (fig. 1).

The DePalma supercharger in service is lubricated from the engine lubricating system; this condition was simulated in these tests by a pressure tank. The case is drilled so that the oil for the bearings and the gears can be supplied through a single duct and the excess drained and returned to the engine pump through another duct. The quantity of oil delivered at each end of the supercharger is metered by an orifice of sufficient size to insure ample flow for all conditions.

The DePalma supercharger used in the present tests had a clearance of approximately 0.006 inch between the tips of the impellers and the case and a clearance of 0.004 inch between the ends of the impellers and the case.

Test apparatus.- The set-up of the supercharger on the dynamometer is shown in figure 3 and a diagrammatic sketch of the equipment used is shown in figure 4. The supercharger was driven by a 200-300 horsepower electric dynamometer. A special gear case bolted directly to the dynamometer shell was used to obtain speeds higher than 3,000 r.p.m. The air quantities were measured by thin-plate orifices placed in the ends of a metal tank $2\frac{1}{2}$ feet in diameter and 15 feet long. Another tank having a capacity of 72 cubic feet and sufficient strength to withstand the pressure during the tests with reduced pressure at the intake was placed in the air duct between the supercharger and the orifice tank to damp the pressure pulsations caused by the supercharger. A third tank, with a

capacity of 12.5 cubic feet, was connected to the discharge side of the supercharger for use in tests with a pressure higher than atmospheric at the discharge. Throughout this report atmospheric pressure refers to sea-level pressure. A valve was placed between the orifice and the depression tank to regulate the intake pressure and another valve was placed on the outlet of the high-pressure tank to regulate the discharge pressure.

The temperatures were measured by liquid-in-glass thermometers calibrated for proper immersion; the pressures, by liquid manometers of suitable sensitivity; the speed of the dynamometer, by an electrically operated revolution counter and stop watch; and the clearance, by means of a gage (fig. 5) designed to measure the clearance while the supercharger is running. The body A of the gage was screwed into the supercharger housing after which the insulated pointer C was regulated by the cap screw B until it was flush with the inside of the housing. The clearance was the amount the pointer C had to be screwed in from the position where it was flush with the inside of supercharger case until it made contact with the impeller. When the pointer made contact with the impeller, it closed an electric circuit; the closing was indicated by the glowing of a neon bulb in the circuit. The amount the pointer had moved was indicated by the micrometer graduations on the cap screw B. The clearance gage operated very satisfactorily and measured the clearances accurately to within ±0.0005 inch.

Tests.- The following data were obtained during these tests:

Temperature of the air at the right and left orifices.

Temperature of the air at the inlet and outlet of the supercharger.

Room temperature

Pressure drop across the right and left orifices.

Pressure in the depression tank (during the tests with atmospheric pressure at the exhaust).

Pressure in the high-pressure tank (during the tests with atmospheric pressure at inlet).

Barometric pressure.

Speed of the dynamometer.

Dynamometer scale reading.

Clearance measurements.

The pressure difference across the supercharger during these tests was regulated by the valves at the intake and exhaust of the supercharger. The pressure difference was limited to 15 inches of mercury because of the high discharge-air temperatures resulting from operating with room temperature at the inlet.

The method of computing the results of the performance tests is given in reference 1. Durley's coefficients, modified for reversal of flow, were used for the thin-plate orifices to determine air weights (reference 4). The plotted values of the DePalma test data are given in the present report with enough data from tests of an N.A.C.A. Roots supercharger to show the comparative performance.

RESULTS AND DISCUSSION

Figure 6 shows the horsepower required to operate the supercharger at various speeds and with various pressure differences between the intake and the discharge. Note that the horsepower required by the DePalma supercharger increases more rapidly than that required by the N.A.C.A. Roots as the speed is increased, especially at the low pressure differences and at speeds greater than 3,000 r.p.m. The difference in mechanical friction between the two superchargers should be very small; that of the N.A.C.A. Roots probably was slightly higher as it had one more pair of gears. The excessive power requirements of the DePalma supercharger during high-speed operation and low pressure differences show that either the intake opening, the discharge opening, or both are too small for high-speed operation. That this condition does not exist at a speed of 3,000 r.p.m. or less is substantiated by the close agreement of the power requirements of the DePalma and the N.A.C.A. superchargers at these speeds. The performance of the latter is based on a 4-inch supercharger of 0.185-cubic-foot displacement and is corrected

to the same displacement as the DePalma on the basis that the power required varies directly as the capacity.

Throughout this report a hypothetical N.A.C.A. supercharger of the same displacement as the DePalma supercharger is referred to as an "N.A.C.A. supercharger." The area of the discharge and the intake openings of the DePalma supercharger are 6.3 and 8.8 square inches, respectively; the areas of the discharge and the intake openings of the N.A.C.A. supercharger, corrected to a supercharger displacement of 0.101 cubic foot, are each 12.1 square inches. That the difference in the power required at high speeds by a DePalma supercharger and an N.A.C.A. supercharger is smallest at the high pressure differences indicates that the discharge opening of the DePalma is too small. When the discharge passage is restricted, the backflow is less than it is with large passages and therefore more of the compression is caused by the movement of the impellers and less by the backflow of the high-pressure air. Because of the fact that more of the compression is caused by the movement of the impellers in a supercharger with a restricted discharge, excessive pressures may be built up in the case when the pressure difference across the impellers is small and the speed high. In the examination of these curves it must be remembered that they are not appreciably affected by any difference or change in clearance because they are based on speed and pressure difference and are not appreciably influenced by the weight or volume of air that slips back between the impellers.

The weight of air delivered by a DePalma supercharger and an N.A.C.A. supercharger of the same displacement is shown by the curves in figure 7. The curves for the N.A.C.A. Roots supercharger of 0.101-cubic-foot displacement are based on the performance of a 0.185-cubic-foot displacement N.A.C.A. supercharger with 0.007-inch tip clearance and 0.010-inch end clearance and on the assumption that the air weight varies directly with the size and that the slip is directly proportional to the clearance area. Because the ratio of the clearance area to the capacity increases when the capacity is reduced, the quantity of air that slips back between the impellers becomes a larger percentage of the air delivered. The curve for the DePalma supercharger at 15 inches of mercury pressure difference was extrapolated from 4,000 to 6,000 r.p.m. because, for speeds over 4,000 r.p.m., the discharge air temperatures were higher than 200° F. The clearance loss-

es may be obtained from these curves in terms of the speed required to maintain the desired pressure difference at zero air delivery. The difference in the slope of the curves shows the relation between the intake and discharge losses for the two types of superchargers at speeds up to 6,000 r.p.m.

On the basis of the horsepower curves in figure 6 and the air-weight curves in figure 7, the power required by a DePalma supercharger of sufficient size to compress one pound of air per second at a speed of 3,000 r.p.m. and at a pressure difference of 12 inches of mercury is 62.4 horsepower; whereas the N.A.C.A. supercharger would require 46.5 horsepower, a ratio of 1.34. At speeds lower than 3,000 r.p.m. and at 12 inches of mercury pressure difference, the ratio of power will be greater; at speeds higher than 3,000 r.p.m., the ratio will be smaller.

The change in clearance, due to temperature, between the impellers and the impeller housing at various pressure differences is shown in figure 8 for the 8.25-inch N.A.C.A. and the DePalma superchargers. This difference in clearance is explained by the relative thermal coefficient of expansion of the metals used. Previous tests with steel and aluminum-alloy impellers have shown that there is a negligible change in clearance due to centrifugal force at speeds less than 3,000 r.p.m. At high pressure differences the supercharger reaches temperatures higher than 200° F. and, inasmuch as the thermal coefficient of linear expansion for annealed steel is roughly one-half that of aluminum alloys, the clearances would be affected in like proportion. The curves show that, if a metal of appreciably lower coefficient of expansion is used in the construction of the impellers than is used in the case, the clearances will increase with an increase in pressure ratio. If a metal of greater coefficient of expansion is used in the impellers than is used in the case, the clearances will decrease with an increase in pressure ratio. From these curves it follows that, if other factors such as warping and growing of the metals of the case and impellers are neglected, the most uniform clearances can probably be maintained for all operating conditions when the case and the impellers are made of the same material.

The slip speeds for the DePalma supercharger and the 4-inch N.A.C.A. supercharger with the inlet blocked are shown in figure 9. In this figure is included the slip speed for an N.A.C.A. supercharger of the same displace-

ment as the DePalma and with 0.007-inch tip clearance and 0.010-inch end clearance. The curve for this supercharger is based on the curve for the 4-inch supercharger with proper allowance for the difference in clearance area and displacement. Note that the slip speed for the DePalma increases more rapidly as the pressure difference is increased than the slip speed for the N.A.C.A., which is in agreement with the measurements of change in clearance given in figure 8.

The volumetric efficiency curves in figure 10 show that the efficiency of the DePalma supercharger is considerably lower than the efficiency of the 4-inch N.A.C.A. supercharger. The volumetric efficiency of the DePalma is low because of the high slip speed and intake and discharge losses. At 12 inches of mercury pressure difference the volumetric efficiency of the hypothetical N.A.C.A. supercharger of 0.101-cubic-foot displacement would be about 5 percent lower at 6,000 r.p.m. and 10 percent lower at 3,000 r.p.m. than that of the 4-inch N.A.C.A. supercharger. These values are obtained from the slip-speed curve shown in figure 9, which, for a pressure difference of 12 inches of mercury, amounted to a difference in slip speed of about 300 r.p.m. For the lower pressure differences the effect is less, being reduced to zero at no pressure difference.

The volumetric efficiency of a Roots-type supercharger as determined from slip-speed measurements should be equal to that determined from actual air measurements, provided that there are no intake losses and that the slip speed obtained with the intake to the supercharger blocked is the same as the speed existing in actual tests. The truth of the latter assumption is doubtful because of the possible difference in clearance for the two conditions and because of the effect of the small discharge opening at high speeds. The difference in clearance, however, should be small. The group of curves in figure 11 shows the volumetric efficiency for the DePalma supercharger as determined from slip-speed measurements and from actual air measurements. Note that at the low pressure difference and at high speeds there is considerable discrepancy between the efficiencies determined by the two methods. As the efficiencies determined from air measurements are the lower, the slip-speed readings used in the other method must be low. From these slip-speed and air measurements it follows that the slip speeds which exist when the supercharger is delivering air are much higher than those obtained in tests by blocking off the intake. Values of

slip-speed measurements under operating conditions may be obtained from the curves in figure 7 for zero air delivery at various pressure differences. The small discharge opening on the DePalma restricts the flow so that the pressure within the case is higher than the manometer indicates. The higher pressure within the case increases the slip. The intake loss undoubtedly causes a small decrease in the volumetric efficiency calculated from actual measurements.

As yet we have considered only test conditions in which sea-level pressure was maintained at the discharge, and pressures lower than sea level at the intake, which are the operating conditions for practically all service superchargers. There are a few installations, especially on racing airplanes, however, in which the supercharger delivers the air to the engine at pressures higher than sea level and takes it in at sea-level pressure or at pressures lower than sea level. Inasmuch as the interest in supercharged engines operating with these pressure conditions is increasing, data are presented for the DePalma supercharger operating with these pressure relations.

The weight of air delivered at various speeds and pressure differences during tests with pressures greater than atmospheric at the discharge is shown by the curves in figure 12. The weight of air delivered for the same speed and pressure difference, except at zero pressure difference, is greater for the boost condition than for the condition with atmospheric pressure at the discharge as shown in figure 7, mainly because the density of the intake air is greater. Note that the slip speed for the boost tests is only about one-half the slip speeds for the tests shown in figure 7.

The power required during the tests with discharge pressures greater than atmospheric should have been the same as for those with atmospheric pressure, provided that the speed and pressure difference were the same. Such would be the case if the inlet and discharge openings of the DePalma were not so small that they restricted the flow; these restrictions affect the power more during boost tests at high speeds than during tests with atmospheric pressure at the discharge. This difference in power is not surprising because of the large difference in slip speed; the higher the slip speed, the less the quantity of air that has to be forced through the discharge opening. A comparison of the horsepower curves in figures 6 and 13 shows that the power required for a given pressure

difference is greater when the discharge pressure is above atmospheric than when the discharge pressure is atmospheric. The difference in power increases with the speed.

The volumetric efficiency curves for the boost tests are shown in figure 14 and a comparison of the volumetric efficiencies for three pressure conditions is shown in figure 15. Note that the volumetric efficiency for the boost tests is considerably higher, especially at high pressure difference, because of the large decrease in slip speeds. Tests conducted by the Clarke Thomson research laboratory, the results of which have not been published, show that a difference in slip, due to the difference in pressure ratio and density can be expected, the slip with atmospheric pressure at the inlet being less than that with atmospheric pressure at the exhaust. The difference in slip calculated by the method of the Clarke Thomson research laboratory, however, is less than the observed difference, which indicates that the pressure inside the supercharger is higher with atmospheric pressure at the exhaust than it is with atmospheric pressure at the inlet.

CONCLUSIONS

The results of the tests of a DePalma supercharger indicate that:

1. If warping and growing of the metals of the case and impellers are neglected, the most uniform clearances can probably be maintained for all operating conditions when the case and the impellers are constructed of metals that have the same coefficient of expansion, which will reduce the slip losses.

2. A Roots supercharger of 0.101-cubic-foot displacement should have intake and discharge openings of at least 12 square inches in order not to minimize the flow at high speeds.

3. For the DePalma supercharger the volumetric efficiency during tests at high pressure difference is greater when the discharge pressures are higher than atmospheric than when the discharge pressures are equal to atmospheric pressure.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 3, 1936.

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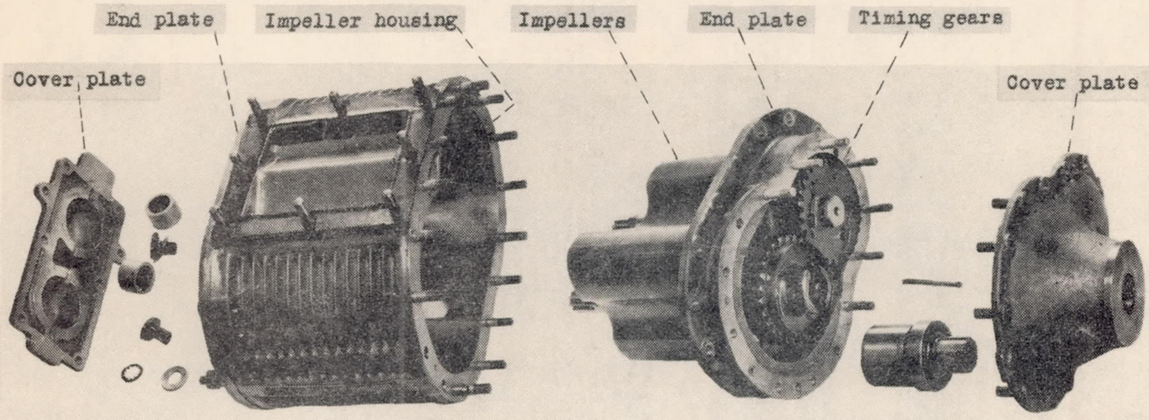

Figure 1.- The details of construction of a DePalma Roots supercharger

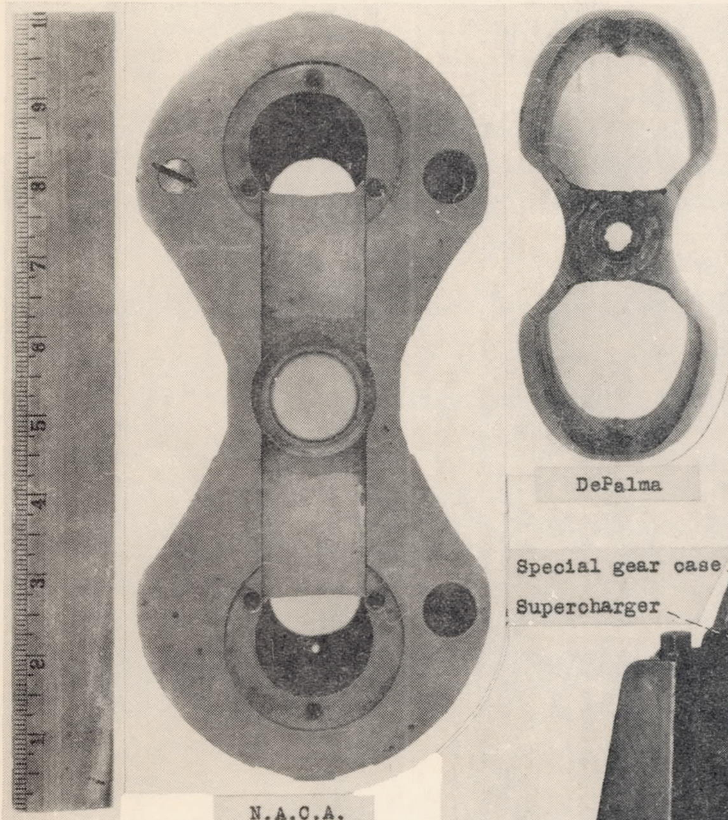

Figure 2.- Details of construction of steel impeller for the DePalma supercharger and the magnesium - alloy impeller for the N.A.C.A. supercharger.

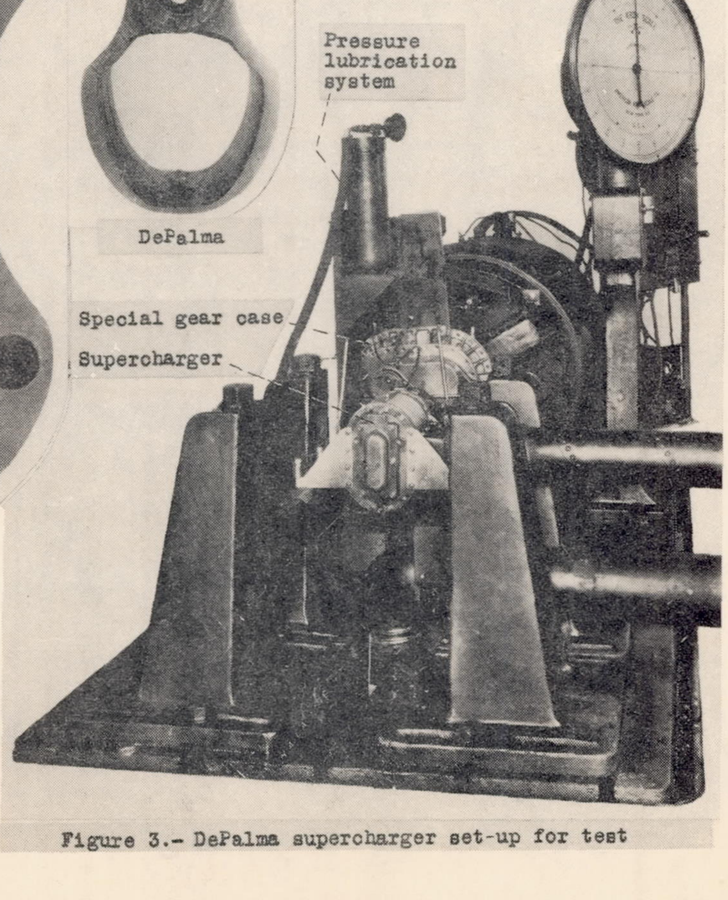

Figure 3.- DePalma supercharger set-up for test

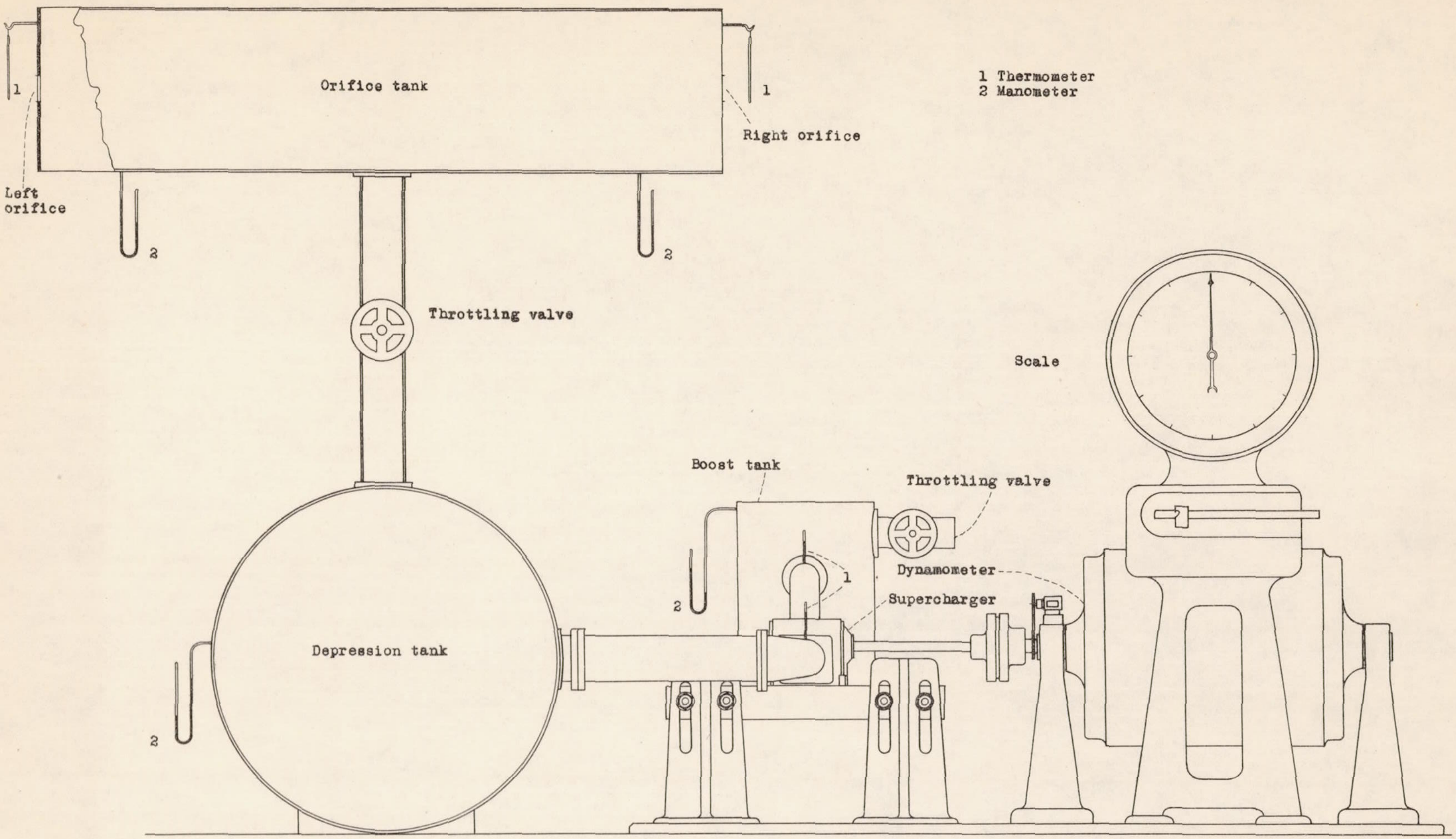

Figure 4.- Diagrammatic arrangement of equipment.

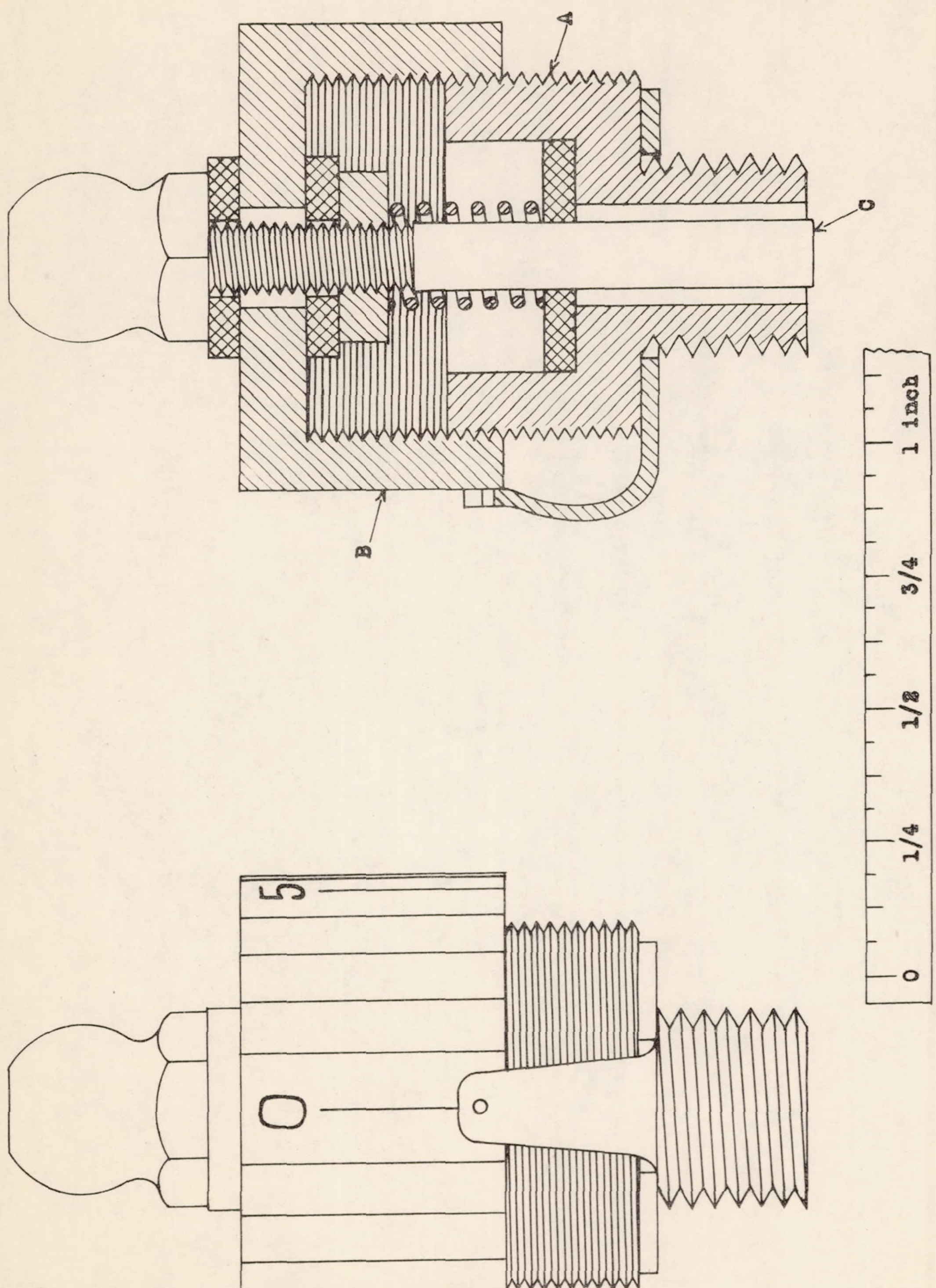

Figure 5.- Details of construction of the clearance gage.

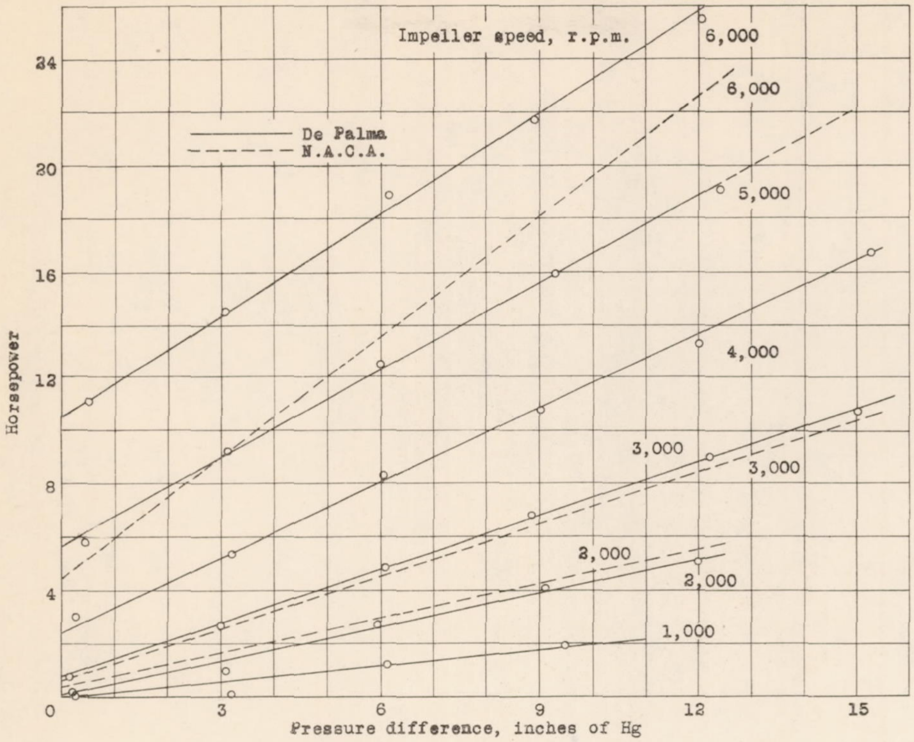

Figure 6.- Horsepower required at various speeds and pressure differences by a De Palma and a hypothetical N.A.C.A. supercharger of the same displacement with atmospheric pressure at the discharge.

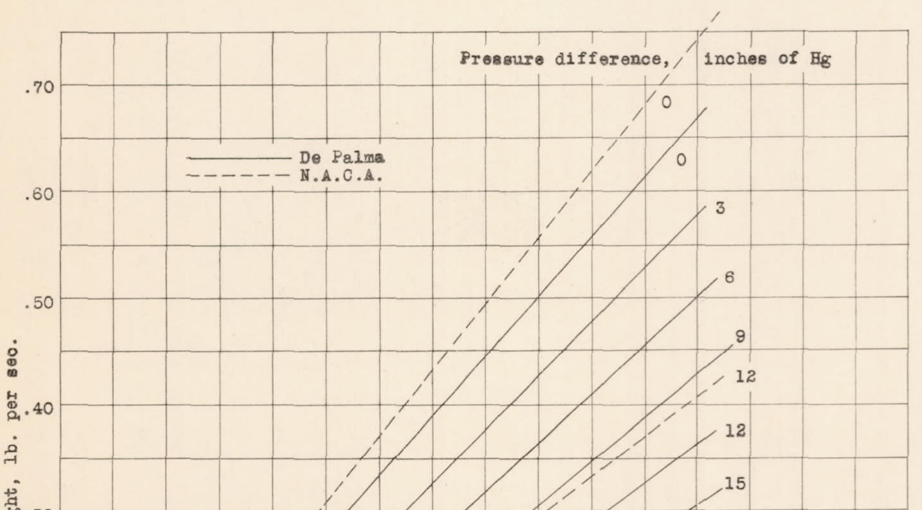

Figure 7.- Air weight delivered at various speeds and pressure differences by a De Palma and a hypothetical N.A.C.A. supercharger of the same displacement with atmospheric pressure at the discharge.

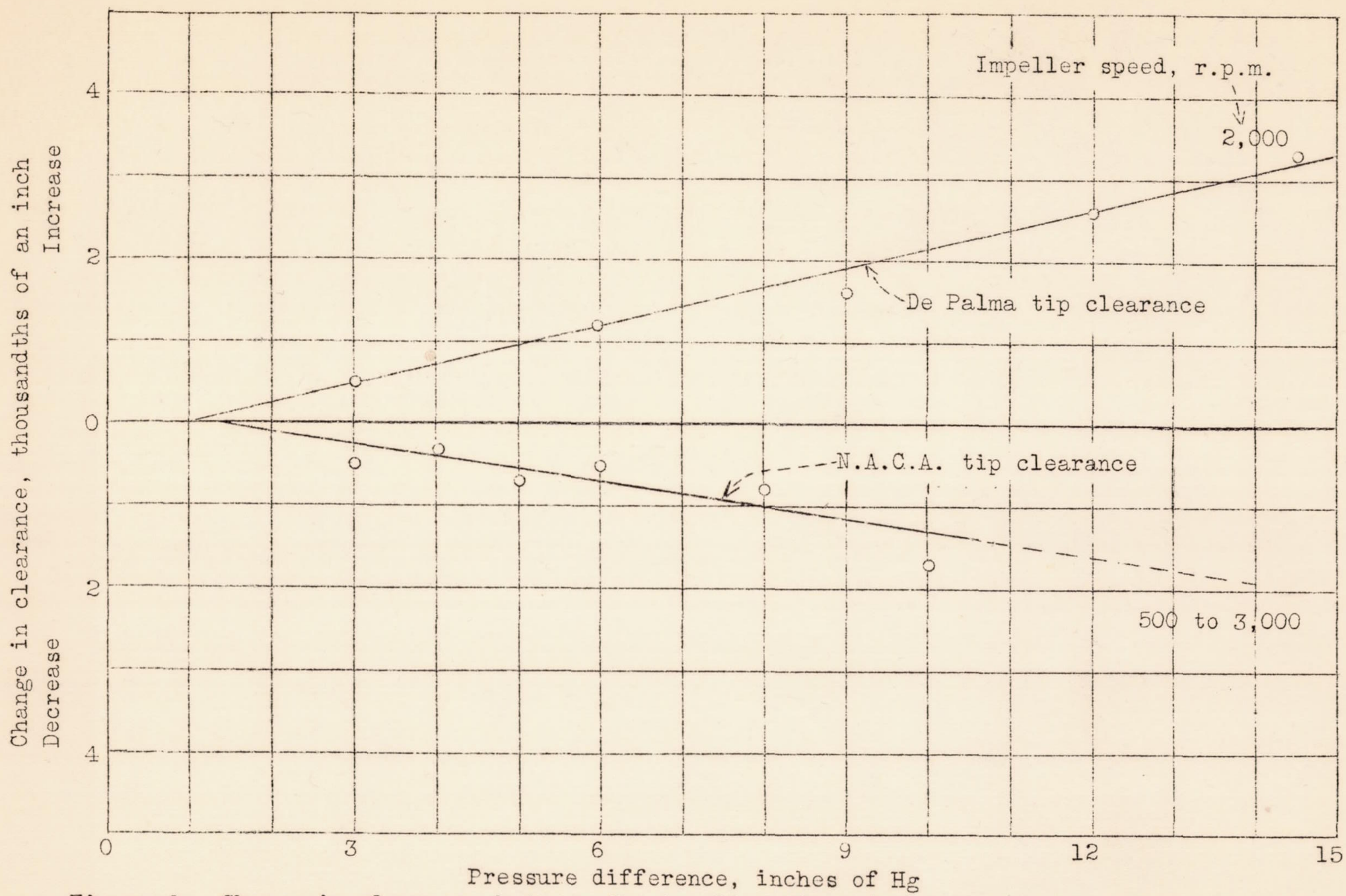

Figure 8.- Change in clearance between the impeller tip and the housing at various pressure differences for an 8.25 inch N.A.C.A. supercharger with magnesium-alloy impellers and a De Palma supercharger with steel impellers.

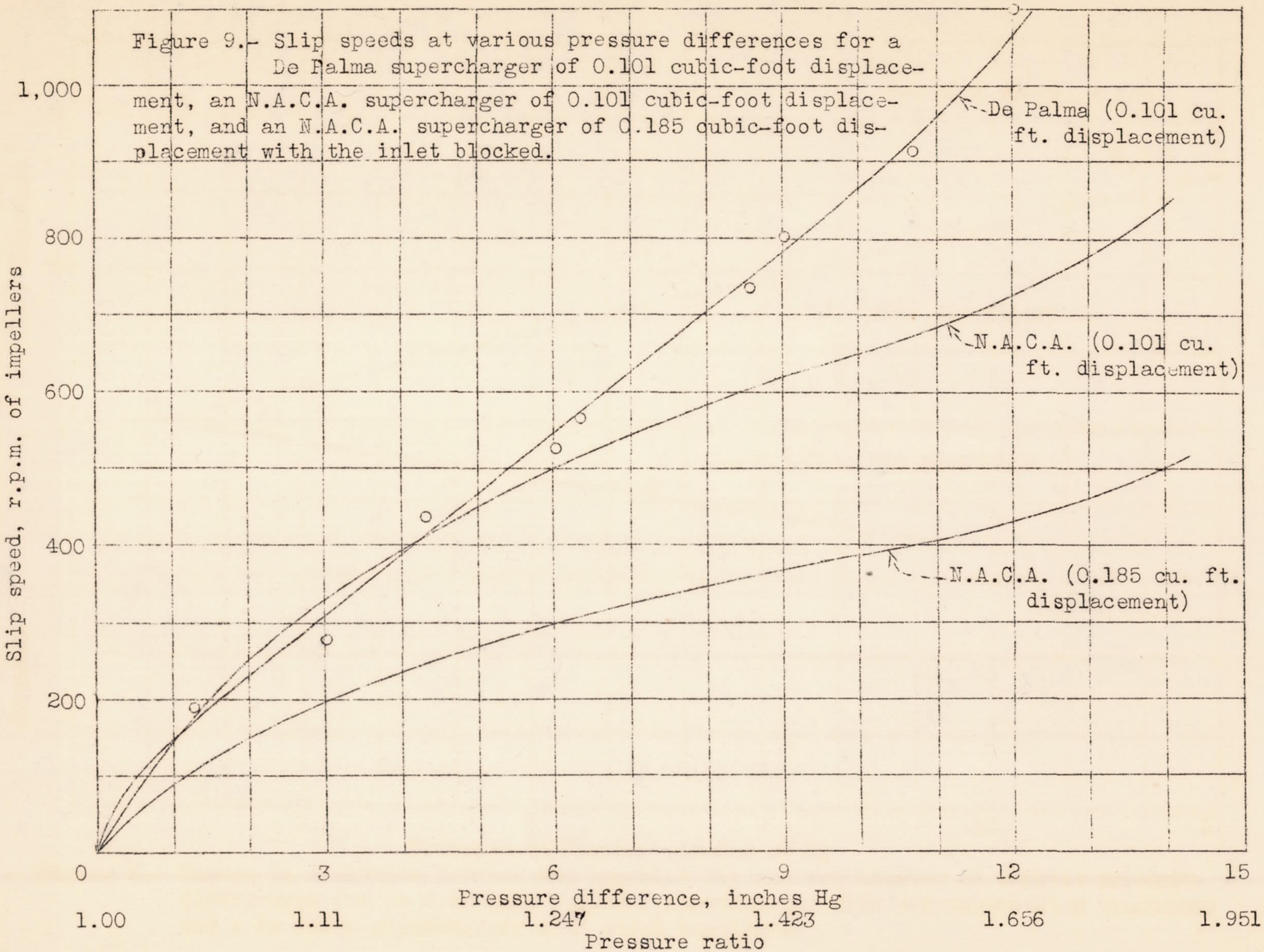

Figure 9.- Slip speeds at various pressure differences for a De Palma supercharger of 0.101 cubic-foot displacement, an N.A.C.A. supercharger of 0.101 cubic-foot displacement, and an N.A.C.A. supercharger of 0.185 cubic-foot displacement with the inlet blocked.

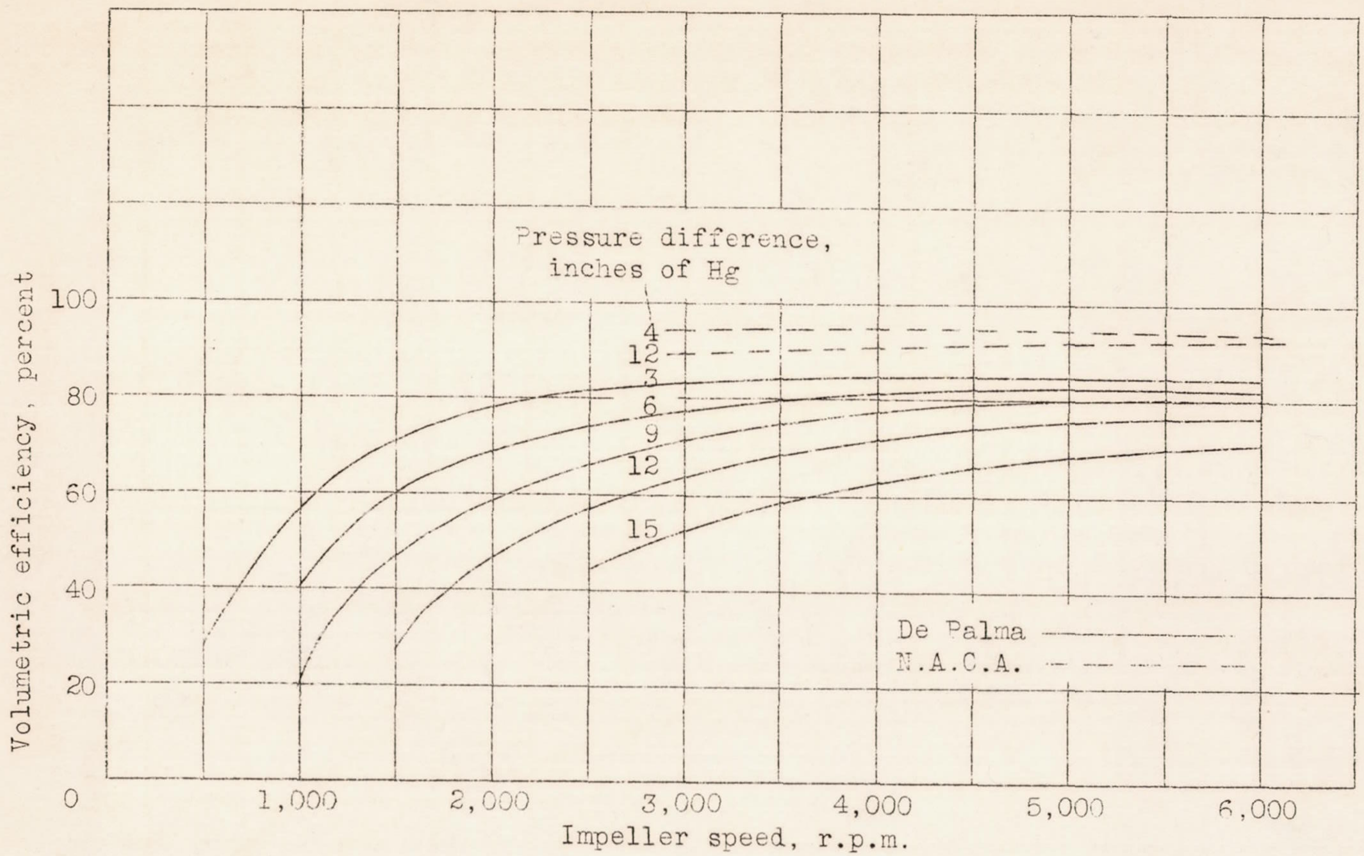

Figure 10.- Volumetric efficiency at various speeds and pressure differences of a De Palma supercharger and a 4-inch N.A.C.A. supercharger with atmospheric pressure at the discharge.

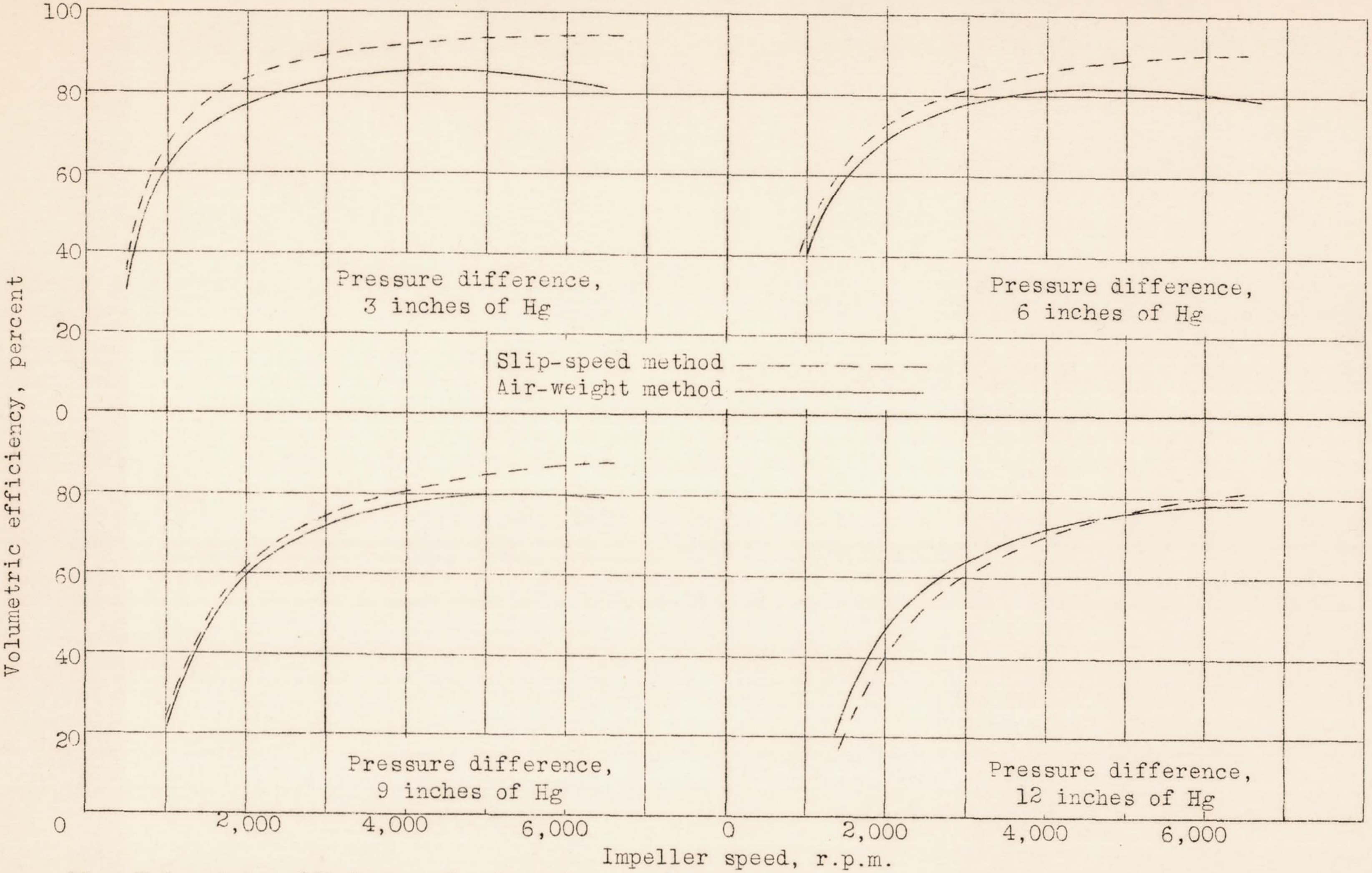

Figure 11.- Volumetric efficiency of a De Palma supercharger at various speeds and pressure differences with atmospheric pressure at the discharge as determined from slip-speed measurement and air measurement.

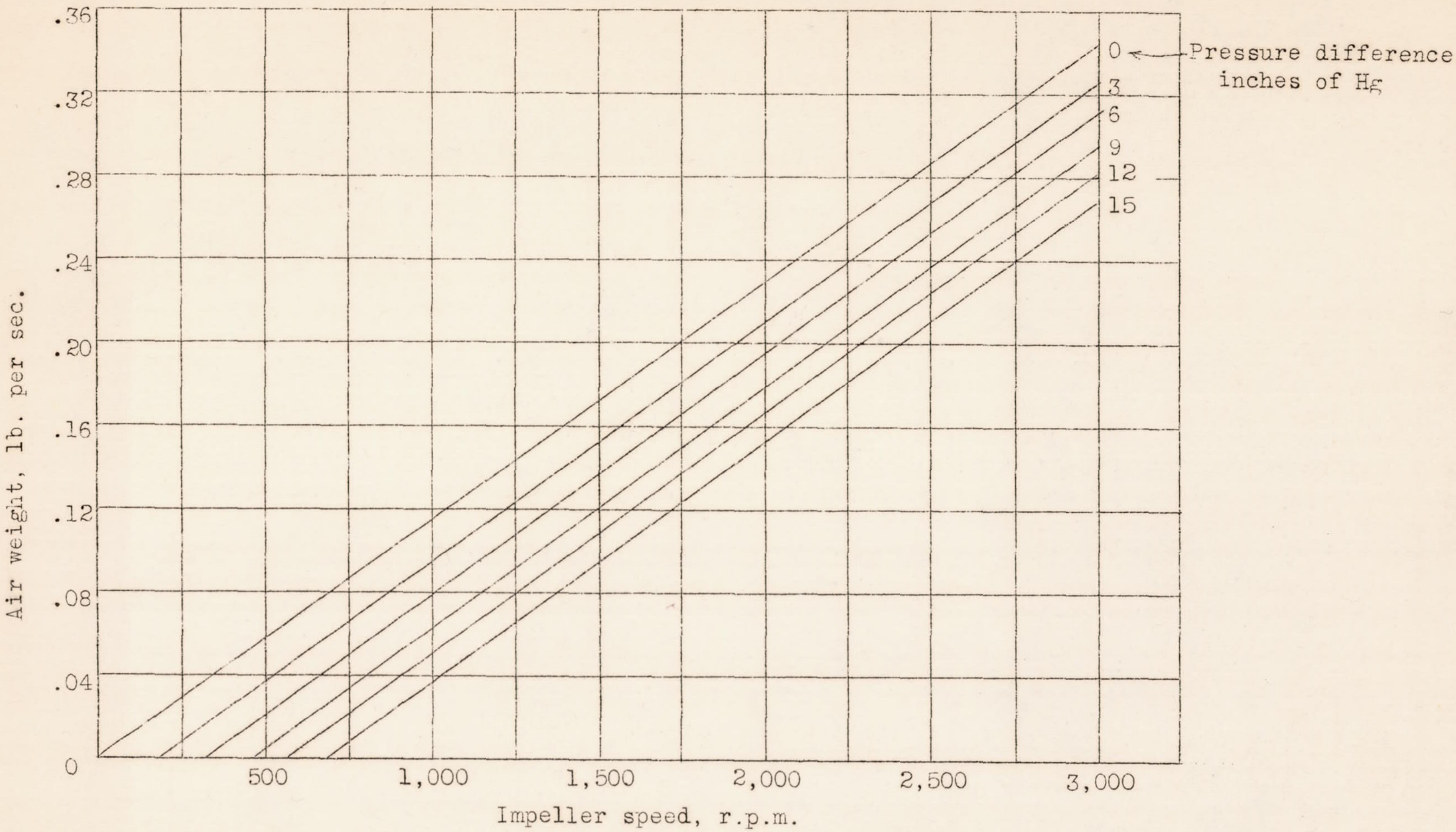

Figure 12,- Air weight delivered at various speeds and pressure differences by a De Palma supercharger with atmospheric pressure at the intake.

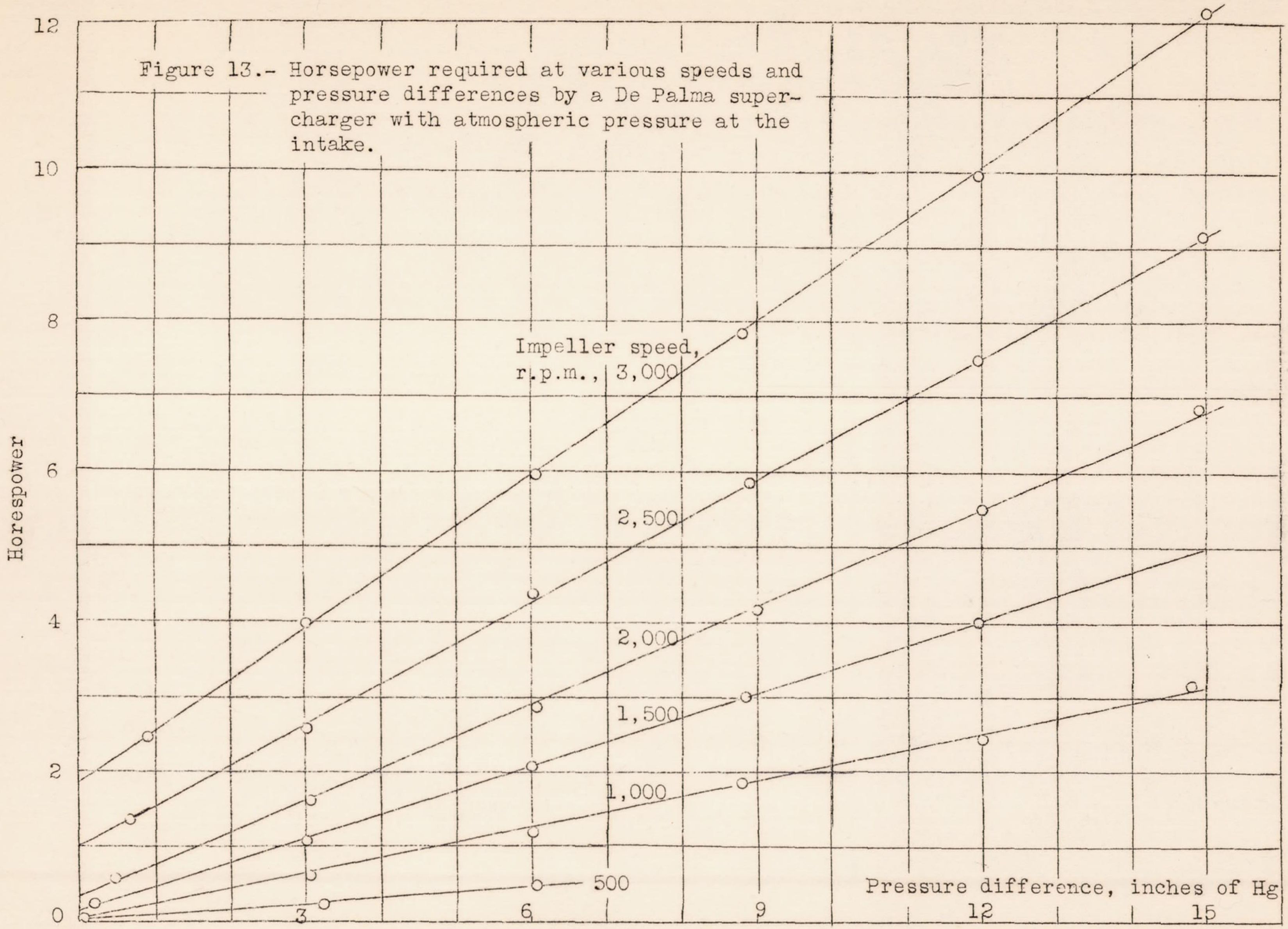

Figure 13.- Horsepower required at various speeds and pressure differences by a De Palma supercharger with atmospheric pressure at the intake.

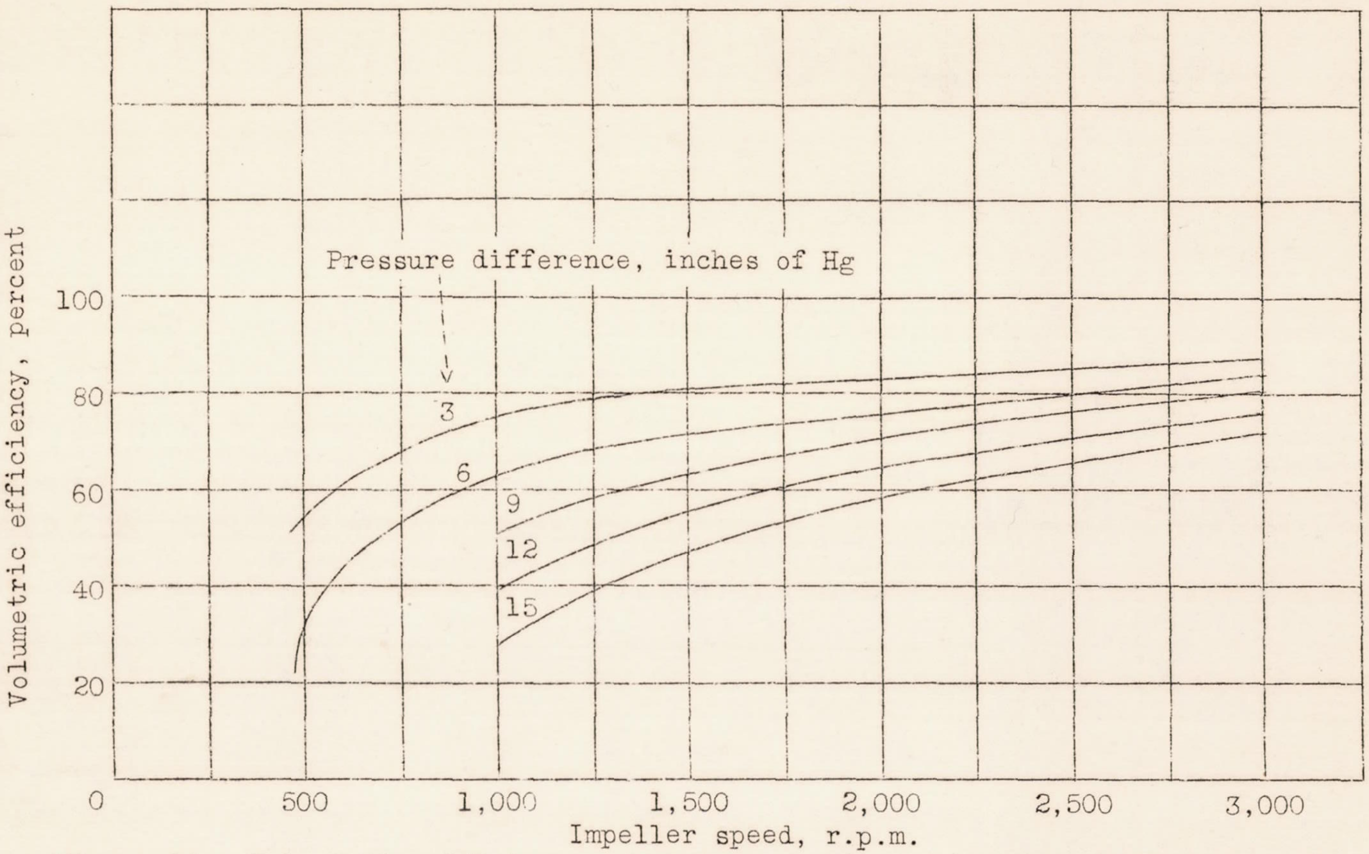

Figure 14.- Volumetric efficiency at various speeds and pressure differences of a De Palma supercharger with atmospheric pressure at the intake.

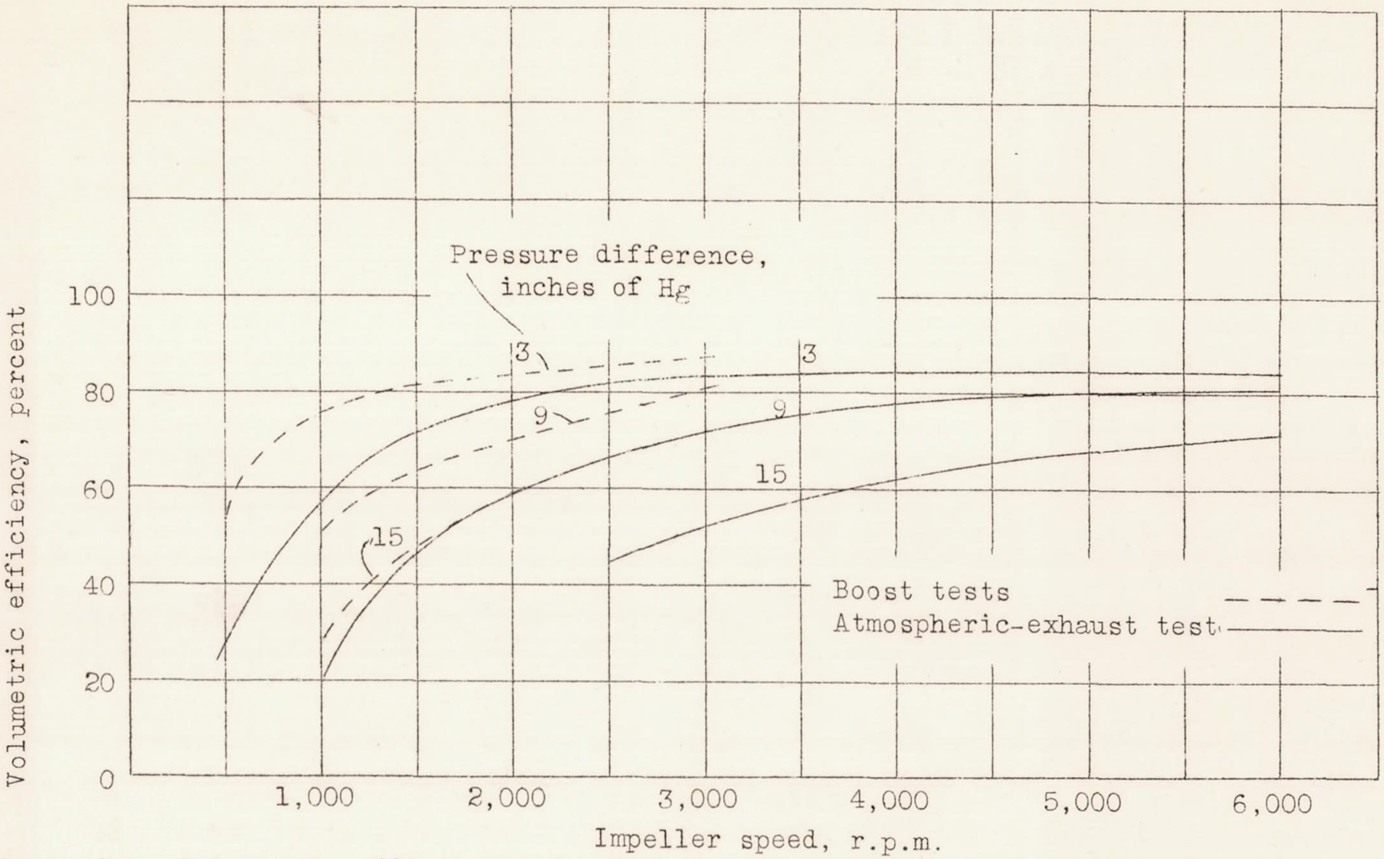

Figure 15.- Volumetric efficiency of a De Palma supercharger with atmospheric pressure at the discharge compared with the volumetric efficiency with atmospheric pressure at the intake.